ELSEVIER
Available online at www.sciencedirect.com
SciVerse ScienceDirect
Energy Procedia 16 (2012) 1891 – 1898
Energy Procedia

2012 International Conference on Future Energy, Environment, and Materials

The Evaluation Grades of Health Risk Based on the SPA Model

Yu Deng, Fuquan Ni, Fuquan Ni

Key Laboratory of Sichuan Agricultural Environment and Engineering
Sichuan Agriculture University, SICAU
Ya'an, China
State Key Laboratory of Hydraulics and Mountain River Engineering
Sichuan University, SCU
Chengdu, China

Abstract

In this study, Mingshan county—a typical hilly region located on the western edge of the Sichuan basin was selected as the research area. Based on the health risk assessment of Cr(VI), nitrate, fluoride and iron in 41 rural drinking water resources, applying the model recommended by the U.S. Environmental Protection Agency (U.S.EPA), the evaluation grades of health risk associated with drinking water quality (HRWQ) was developed, and the Connection Degree (CD) and the weight of each index of the samples were calculated. And by evaluating them with the criterion of confidence level, Set Pair Analysis (SPA) was established. In this study, it could be seen that the HRWQ of most the resources in the area were of low-medium risk within grade I–III while the HRWQ of some other resources were in a less safe state of medium-high risk.

Keywords-health risk; set pair analysis; evaluation grade; Connection Degree; Membership Degree(MD)

1. Bankground

Since the 1980s and the 1990s, industrial and urban pollution has transferred significantly to the rural area, deteriorating the water environment in towns and villages resulting in frequent occurrence of severe water pollution emergencies. A wide range of water resource pollution and damage has been a serious threat to the health and life of the rural residents, posing a great challenge to our country in rural drinking water safety [1]. Currently, many scholars, both at home and abroad, are concerned about water quality issues and most studies have focused only on the evaluation of single water resource such as the reuse of

 doi:10.1016/j.egypro.2012.01.289

waste water in the urban area [2, 3, 4]. So far, little researches report on health risk evaluation grade of regional water quality has been published yet.

In fact, there are quantities of uncertain factors in the assessment of HRWQ. Put forward by Chinese scholar Keqin Zhao and based on the idea of unity of the opposites, the SPA model can analyze the inner relations of the research system both whole and part. The central idea is that methods including dialectical analysis and mathematical treatment were applied to handle the certainty and the uncertainty of the system and to analyze them from three aspects---identity, discrepancy and contrary, which are connected and interactional under certain condition [5]. Recently, some scholars used the SPA model to evaluate the water quality assessment and many results were obtained [6]. In this study, based on the U.S.EPA health risk assessment model applying SPA theory, with the maximum MD as evaluation criterion, the HRWQ was quantitatively evaluated by calculating the CD of each ED (Evaluation Degree) and the utility value of risk evaluation data was reflected with entropy in the decision of the weight of evaluation index. Therefore, the ED of the HRWQ is comprehensive and objective.

2. Procedures

2.1 SPA theory

The basic principle of the SPA is to analyze the set pair of H=(A,B), the combination of sets A and B, based on the requirements of the issue discussed. N features were obtained, among which S features were common to both A and B. There were P features contrasted in sets A and B, and the rest F=N-S-P features were discrepant. The CD $\mu_{(A\text{-}B)}$ was applied to fully reveal the connection of sets of A and B [7, 8],

$$\mu_{(A-B)} = \frac{S}{N} + \frac{F}{N}i + \frac{P}{N}j = a + bi + cj \tag{1}$$

There, $a + bi + cj = 1$, $i \in [-1,1]$, $j = -1$.

Where, i is the coefficient of the discrepancy degree whose value is uncertain; j is the coefficient of the contrary degree. Formula (1) shows the connection and interaction of the identity, discrepancy and contrary, and under certain condition, they might transform into each other. When i is 1, uncertainty transforms into identity and when -1, uncertainty transforms into contrary and when in interval (-1, 1), it reflects respectively the proportion of certainty and uncertainty [9, 10].

2.2 The SPA model of health risk evaluation

A set pair of the evaluation index of the HRWQ in the region and the ED should first be developed before applying the SPA model to evaluate the HRWQ in the region. Then the grade of the evaluation factor was judged if it was within the grade and this situation was considered as identity and the CD was 1; if it was in the standard grade of adjacency, it was considered as contrary and the CD was -1. The CD calculation methods are as follows.

1) When the evaluation index is in grade I,

$$\mu_{i1} = \begin{cases} 1 & x \in \left[0, S_{i(1)}\right) \\ 1 + \dfrac{2(x - S_{i(1)})}{S_{i(1)} - S_{i(2)}} & x \in \left[S_{i(1)}, S_{i(2)}\right) \\ -1 & x \in \left[S_{i(2)}, +\infty\right] \end{cases} \tag{2}$$

2) When the evaluation index is in grade II,

$$\mu_{i2}=\begin{cases}1+\dfrac{2(x-S_{i(1)})}{S_{i(1)}-0} & x\in\left[0,S_{i(1)}\right)\\ 1 & x\in\left[S_{i(1)},S_{i(2)}\right)\\ 1+\dfrac{2(x-S_{i(2)})}{S_{i(2)}-S_{i(3)}} & x\in\left[S_{i(2)},S_{i(3)}\right)\\ -1 & x\in\left[S_{i(3)},+\infty\right)\end{cases} \tag{3}$$

Similarly, the CD calculation equation can be obtained, when the evaluation index is in grade III, IV and V.

3) When the evaluation index is in grade IV,

$$\mu_{i6}=\begin{cases}1 & x\in\left[S_{i(5)},S_{i(6)}\right]\\ 1+\dfrac{2(x-S_{i(5)})}{S_{i(5)}-S_{i(4)}} & x\in\left[S_{i(4)},S_{i(5)}\right)\\ -1 & x\in\left[0,S_{i(4)}\right)\end{cases} \tag{4}$$

$S_{i(1)}$, $S_{i(2)}$, $S_{i(3)}$, $S_{i(4)}$, $S_{i(5)}$ and $S_{i(6)}$ are the corresponding thresholds of ED I, II, III, IV, V and VI respectively.

2.3 Determination of the index weight with Entropy

In the water quality evaluation based on the SPA, without considering the relative magnitude of different index, each index was of equal weight, impacting on the accuracy of the final evaluation. In the information theory, entropy was adopted to measure both the disorder degree of the system and the quantity of useful information provided by data. The more information a certain index carried, the greater role it played in the decision process, and the smaller the entropy was, the lower disorder degree the system had [11]. Therefore, the order degree and utility of the system information obtained can be evaluated by entropy, i.e., the index weight is determined by the judgment matrix consisting of evaluation index value. The steps of the entropy method used to determine the index's weight are as follows [12].

1) Develop the judgment matrix

Suppose there are m water quality samples and each sample has n evaluation indices, judgment matrix R can be written as,

$$R=(r_{\mathrm{st}})_{m\times n} \quad ,\ (\mathrm{s}=1,2,\ldots,\mathrm{m},\ \mathrm{t}=1,2,\ldots,,\mathrm{n}) \tag{5}$$

2) Normalize the judgment matrix

Normalize judgment matrix R, and obtain the normalized matrix Z . The elements of matrix Z are,

$$b_{st}=(r_{st}-r_{\min})\big/(r_{\max}-r_{\min}) \tag{6}$$

r_{max} and r_{mix} correspond respectively to the maximum and minimum value of the same evaluation index in different event.

3) Determine the Entropy of the evaluation index

On the basis of the concept of Entropy, considering the evaluation of HRWQ, the Entropy H_t of the evaluation index can be defined as,

$$H_t=-(\sum_{s=1}^{m}f_{st}\ln f_{st})\Big/\ln m \tag{7}$$

There, $f_{st} = (1+b_{st}) \Big/ \sum_{s=1}^{m} (1+b_{st})$

4) Determine the Entropy weight ω_t of evaluation index

$$\omega_t = (1-H_t) \Big/ (n - \sum_{t=1}^{n} H_t), \text{ and } \sum_{t=1}^{n} \omega_t = 1 \quad (8)$$

2.4 Calculation of the comprehensive CD

$$\mu_{sk} = \sum_{t=1}^{n} \omega_t \mu_{stk} \quad ,(\text{ k}=1,2, \ldots,6) \quad (9)$$

k refers to the ED of the evaluation index, and the comprehensive CD μ_{sk} is within [-1,1].The more identical the sample and the ED k are, i.e., the less discrepant they are, the closer μ_{sk} is to 1 and the sample is to the ED k. The less identical the sample and the ED k are, i.e., the more discrepant they are, the closer μ_{sk} is to -1 and the sample is to other ED.

2.5 Normalization of the MD

It can be seen that the comprehensive CD is a relative discrepancy degree of the Variable Fuzzy Set 'ED k'. The relative MD of samples attached to it can be written as [13],

$$r_{sk} = 0.5 + 0.5\mu_{sk} \quad , (\text{s}=1,2,\ldots,\text{m},\text{k}=1,2,\ldots,6) \quad (10)$$

And the normalized relative MD $r_{sk}^{'}$ is,

$$r_{sk}^{'} = r_{sk} \Big/ \sum_{k=1}^{K} r_{sk} \quad (11)$$

2.6 Determination of the ED

$$k = \max\left\{ k \left| \sum_{j=k}^{K} r_{sj}^{'} > \lambda \right. ,\ 1 \le k \le K \right\} \quad (12)$$

Where, λ refers to the confidence level whose value is in [0.50, 1]. The greater λ the more reliable and accurate the evaluation is [14].

3. Materials

3.1 Overview of the studied area

Mingshan County, Ya'an, is between 103°2' and 103°23' east at longitude and 29°58' and 30°16' north at latitude, with land accounting for 614.27km^2 and the elevation of 548-1456m. Local residents rely on well water, river water. Problems of poor water quality and less water seriously affect the production and living of villagers. The population amounts to 268000. According to the survey in 2004, population of drinking water quality under standards is 85000, in which population of untreated IV-level and super IV-level amounts to 26000, untreated surface water with Bacteriological index exceeding the standards seriously 11000, and seriously polluted and untreated groundwater 9000 [15].

3.2 Sampling

In January 2010, 41 water samples were collected, with comprehensive consideration of the studied area's topography, water system, drinking water resources and the types and distribution of water supply projects. There were 12 surface water samples and 29 groundwater samples in the total 41 samples. YS19500 detector was adopted to determine the physical, chemical and toxicological parameters of the 41 sampling sites, amounting to nineteen items including hardness, color, alkalinity, pH, potassium, manganese, aluminum, ammonia, nitrogen, sulfate, phosphate, chloride, sulfide, iron, zinc, copper, chromium (Cr(VI)), nitrate, nitrite and fluoride. Regarding results of epidemiological surveys, four toxicological indices (Cr(VI), nitrate, fluoride, iron) were screened as the index for the evaluation of the HRWQ, based on whether carcinogens and non-carcinogens in tested area were harm to human health.

4. Results and Analysis

In this study, the strictest standard of acceptable risk grade was adopted. Referring to whether carcinogenic or non-carcinogenic, the HRWQ was divided into six grades, combined with the obtained research results [16]. Details are shown in Table 1, where I represent low risk, II low-medium risk, III medium risk, IV medium-high risk, V high risk and VI extremely high risk.

TABLE I. The Standard of ED

Grade	I	II	III	IV	V	VI
R (Risk)	$[0, 10^{-6})$	$[10^{-6}, 5\times10^{-6})$	$[5\times10^{-6}, 10^{-5})$	$[10^{-5}, 5\times10^{-5})$	$[5\times10^{-5}, 10^{-4})$	$[10^{-4}, 5\times10^{-4})$
HI (Hazard Index)	$[0, 10^{-2})$	$[10^{-2}, 5\times10^{-2})$	$[5\times10^{-2}, 10^{-1})$	$[10^{-1}, 5\times10^{-1})$	$[5\times10^{-1}, 1)$	$[1, +\infty)$

Table 2 shows, referring to the MD criterion and the fuzzy ED developed in this study, the highest ED is grade IV and the lowest is grade I. The HRWQ of two samples are of low risk in grade I, including No.15 and 29, that of another ten samples are of low-medium risk in grade II, including No.3, 10, 16, 18, 20, 21, 25, 27, 28 and 34, that of another 15 ones are of medium risk in grade III including No.6 , 7 ,8 , 9 , 11 , 12 , 14 , 19 , 31 , 32, 33, 35, 36, 38 and 41, and that of the rest 14 ones are of medium-high risk, including No.1 , 2 , 4 , 5 , 13 , 17 , 22 , 23 , 24 , 26, 30, 37, 39 and 40. Among the 41 water resources, the ED of the HRWQ of 27 samples are within grade I-III, accounting 65.85% of the total, which indicates that the HRWQ in most studied area are relatively safe.

Given that the toxic effects of various kinds of poisonous substances on human body are in an additive relation rather than in a cooperative relation, the total health risk equals the carcinogenic risk plus the hazard index, referring to the U.S.EPA [17]. The carcinogenic risk (of Cr(VI)) value is much smaller (up to 2-6 orders of magnitude) than that of the hazard index (of nitrate, fluoride and iron). And in this study, if the method of the U.S.EPA was applied to calculate the total risk, then the importance of the carcinogenic risk in the evaluation of the HRWQ couldn't have been reflected exactly, because, as mentioned above, carcinogenic risk counts such a small proportion in the total risk that it might be ignored completely. It can avoid the problem to some extent and insure the accuracy of the evaluation by dividing the ED of the carcinogenic risk and the hazard index, and calculating the comprehensive CD of different grades in accordance to the weight of each evaluation index, to obtain the evaluation results of the HRWQ.

TABLE II. The Evaluation Results of the HRWQ

Samples	Comprehensive CD						Relative MD						Results
	I	***II***	***III***	***IV***	***V***	***VI***	***I***	***II***	***III***	***IV***	***V***	***VI***	
1	-1.000	-0.886	-0.014	0.503	0.014	-0.618	0.000	0.029	0.246	0.376	0.254	0.096	IV
2	-1.000	-1.000	-0.274	0.527	0.274	-0.527	0.000	0.000	0.182	0.382	0.318	0.118	IV
3	-0.121	0.200	-0.329	-0.200	-0.551	-1.000	0.220	0.300	0.168	0.200	0.112	0.000	II
4	-0.340	-0.340	-0.977	0.180	0.317	-0.840	0.165	0.165	0.006	0.295	0.329	0.040	IV
5	-1.000	-0.340	-0.027	0.158	-0.216	-0.502	0.000	0.173	0.269	0.221	0.206	0.131	IV
6	-0.340	-0.550	0.292	-0.036	-0.952	-1.000	0.193	0.132	0.378	0.282	0.014	0.000	III
7	-0.340	-0.766	0.257	0.180	-0.917	-1.000	0.193	0.068	0.368	0.346	0.024	0.000	III
8	-0.340	-0.442	0.234	-0.071	-0.894	-1.000	0.189	0.160	0.354	0.266	0.030	0.000	III
9	-0.634	-0.010	0.042	-0.250	-0.408	-0.740	0.092	0.247	0.260	0.188	0.148	0.065	III
10	0.158	-0.285	-0.158	-0.653	-1.000	-1.000	0.378	0.234	0.275	0.113	0.000	0.000	II
11	-0.541	-0.119	0.185	0.119	-0.644	-1.000	0.115	0.220	0.296	0.280	0.089	0.000	III
12	0.006	0.025	-0.028	-0.465	-0.979	-1.000	0.283	0.288	0.273	0.150	0.006	0.000	III
13	-0.340	-0.853	-0.682	0.340	0.022	-1.000	0.189	0.042	0.091	0.384	0.293	0.000	IV
14	-0.202	-0.502	-0.601	-0.045	-0.198	-0.713	0.239	0.149	0.120	0.166	0.240	0.086	III
15	1.000	-1.000	-1.000	-1.000	-1.000	-1.000	1.000	0.000	0.000	0.000	0.000	0.000	I
16	0.158	-0.575	-0.462	-0.437	-0.696	-1.000	0.387	0.142	0.180	0.188	0.102	0.000	II
17	0.158	-0.780	-0.870	-0.158	-0.288	-1.000	0.378	0.072	0.042	0.275	0.233	0.000	IV
18	0.158	-0.391	-0.382	-0.620	-0.776	-1.000	0.387	0.204	0.207	0.127	0.075	0.000	II
19	-0.208	-0.079	-0.123	-0.435	-0.669	-1.000	0.227	0.264	0.252	0.162	0.095	0.000	III
20	-0.340	0.189	0.054	-0.556	-0.714	-1.000	0.182	0.327	0.290	0.122	0.079	0.000	II
21	0.158	-0.524	-0.426	-0.341	-0.732	-1.000	0.369	0.152	0.183	0.210	0.086	0.000	II
22	0.158	-0.853	-0.869	-0.158	-0.289	-1.000	0.387	0.049	0.044	0.282	0.238	0.000	IV
23	0.158	-0.853	-0.942	-0.656	-0.470	-0.502	0.423	0.054	0.021	0.126	0.194	0.182	IV
24	-0.340	-0.780	-0.623	0.340	-0.037	-1.000	0.185	0.062	0.106	0.376	0.271	0.000	IV
25	0.656	0.012	-0.952	-0.656	-0.704	-1.000	0.494	0.301	0.014	0.103	0.088	0.000	II
26	-0.340	-1.000	-0.780	0.130	0.120	-0.790	0.198	0.000	0.066	0.338	0.335	0.063	IV
27	-0.156	-0.048	-0.418	-0.437	-0.740	-1.000	0.397	0.121	0.200	0.193	0.089	0.000	II
28	-0.515	0.158	-0.730	-0.656	-0.785	-1.000	0.359	0.373	0.087	0.111	0.069	0.000	II
29	0.470	-0.502	-1.085	-0.656	-0.696	-1.000	0.581	0.197	-0.034	0.136	0.120	0.000	I
30	0.158	-1.000	-0.930	-0.158	-0.228	-1.000	0.407	0.000	0.025	0.296	0.272	0.000	IV
31	0.158	-1.000	-0.468	-0.158	-0.690	-1.000	0.407	0.000	0.187	0.296	0.109	0.000	III
32	-0.266	-0.502	-0.550	0.044	-0.384	-1.000	0.267	0.142	0.129	0.287	0.176	0.000	III
33	-0.502	-1.000	0.560	0.502	-0.859	-1.000	0.135	0.000	0.421	0.406	0.038	0.000	III
34	0.585	-0.282	-0.815	-0.656	-0.770	-1.000	0.284	0.348	0.090	0.167	0.111	0.000	II
35	-0.144	0.355	-0.664	-0.158	-0.480	-1.000	0.189	0.223	0.116	0.292	0.180	0.000	III
36	0.158	-0.707	-0.724	-0.158	-0.434	-1.000	0.369	0.093	0.088	0.269	0.181	0.000	III
37	0.158	-1.000	-0.810	-0.158	-0.348	-1.000	0.407	0.000	0.067	0.296	0.230	0.000	IV
38	0.158	-0.596	-0.520	-0.415	-0.638	-1.000	0.218	0.185	0.219	0.212	0.166	0.000	III
39	-0.340	-0.958	0.304	0.0-99	-0.356	-0.801	0.198	0.013	0.208	0.329	0.193	0.060	IV
40	-0.226	-1.000	0.097	-0.656	-0.171	-0.502	0.409	0.000	0.001	0.121	0.293	0.176	IV
41	-0.340	-0.886	0.052	0.226	-0.712	-1.000	0.198	0.034	0.315	0.367	0.086	0.000	III

5. Conclusions

The key for the evaluation is to determine the CD. From the evaluation, it can be seen that the HRWQ of the most at the studied area are within grade I-III indicating the regional drinking water is in critical state of safety. There are fourteen water resources in grade IV which indicates that the HRWQ of certain resources are of medium-high risk and therefore in a relatively unsafe state. The chemical pollutant Cr (VI) exceeds the legal limit in all studied areas except No.15 and its carcinogenic risk is 8.34 to 27.1 times the control risk value recommended by the U.S.EPA.

As a comprehensive evaluation method, SPA can reflect the overall state and make a quantitative evaluation. When applying the U.S.EPA model, the difference in the order of magnitude is so high sometimes that some sampling data might be ignored, while SPA can totally avoid such problems ensuring the reliability and accuracy of the evaluation. In addition, all the single indicators are combined together organically by the calculation of the comprehensive CD, making the evaluation easier to understand.

References

[1] K. Jiang, “Thoroughly implement the scientific development view to ensure drinking water safety for rural people,” Beijing: China Water, 2008, pp.1-12. (in Chinese)

[2] S. Hellel, and F. Badri, “Control of pathogenic microorganisms in wastewater recycling and reuse in agriculture,” Handbook Water and Wastewater Microbiology, 2003; 241-262

[3] H.J. Jeong, W.T. Hwang, E.H. Kim, and M.H. Han, “Radiological risk assessment for an urban area: Focusing on a drinking water contamination,” Annal Nuclear Energy, vol. 36 Sep.2009, pp.1313- 1318, doi:10.1016/j.anucene.2009.07.008

[4] C. Fan, G. Wang, Y. Chen, and C. Ko, “Risk assessment of exposure to volatile organic compounds in groundwater in Taiwan,” Science of The Total Envirnoment, vol. 407, Mar. 2009, pp.2165-2174, doi:10.1016/j.scitotenv.2008.12.015

[5] F. Xu , X. Zheng , J. Zhang , Z. Fu , and X. Zhang, “A hybrid reasoning mechanism integrated evidence theory and set pair analysis in Swine-Vet,” Expert Systems with Applications,vol.37, Oct.2010,pp.1-8, doi:10.1016/j.eswa.2010.03.008

[6] M.C. Li, G.Y. Zhang, S.X. Liang, and Z.C. Sun, “Marine water quality assessment’s nonlinear set pair analysis method,” Environment Materials and Environment Manangement, vol. 113, Jun. 2010, pp. 85-190, doi:10.4028/www.scientific.net/AMR. 113- 116.185

[7] Z. Zhou, G. Li, and Z. He, “Research on Set Pair Extension Jieke of System and Its Application to Business Competition,” Journal of Communication and Computer, vol. 11, Nov. 2006,pp.68-72. (in Chinese)

[8] J. Zhou, “SPA–fuzzy method based real-time risk assessment for major hazard installations storing flammable gas,” Safety Science, vol.48,Jul.2010,pp.819–822, doi:10.1016/j.ssci.2010.02.012

[9] M.R. Su, Z.F. Yang, B. Chen, and S. Ulgiati, “Urban ecosystem health assessment based on emergy and set pair analysis—A com- parative study of typical Chinese cities. Ecological Modelling, vol. 220, Sep. 2009, pp. 2341–2348, doi:10.1016/j.ec-olmodel.2009.06.010

[10] F. Ni, G. Liu, Y. Gao, L.Xu, and C. Fu, “Set Pair Analysis forRural Drinking Water Quality ,” Bioinformatics and Biomedical Engineering (iCBBE), IEEE Press, Jun. 2010, pp. 1-5,doi: 10.1109/ICBBE.2010.5515095

[11] C.E. Shannon, "A Mathematical Theory of Communication", Bell System Technical Journal, vol. 27, Jul. 1948, pp. 379-423, 623- 656.

[12] Z. Zou, Y. Yun, and J. Sun, “Entropy method for determination of weight of evaluating in fuzzy synthetic evaluation for water quality assessment indicators,” Journal of Environmental sciences, vol.18,2006,pp.1020-1023.doi:10.1016/S1001-0742(06)60032-6

[13] L. Wu, Y. Guo , S. Chen, and H. Zhou, “Use of variable fuzzy sets methods for desertification evaluation”. Computational Intelligence, Theory and Applications, Sep. 2006, pp. 721-731, doi: 10.1007/3-540-34783-6_70

[14] F. Guo, R.Wang, and H. Sun, “Application of attribute recognition theory in groundwater quality assessment of Heilongdong spring area,” Water Saving Irrigation, vol.11, 2008, pp. 43-45. (in Chinese)

[15] F. Ni, “Study on the drinking water safety decision support system in rural areas in Ya’an region of Sichuan Province,” The 5th International Conference on Urban watershed Management and Mountain River Protection and Development, Vol. 2 2007, pp. 669–677.

[16] H. Zhu, X. Yuan, G. Zeng, H. Jiang, L. Jie, N. Zhao, Z. Zhao, "An integrated fuzzy model based on interval numbers for assessment of environmental health risks of water sources," Journal of Environment Science, vol. 29, Jul. 2009, pp.1527-1533. (in Chinese)

[17] F. Ni, G. Liu, S. Yang, and J. Ye, "Health risk assessment of rural water sources on the western edge of Sichuan Basin," Progress in Natural Science, vol. 19, Nov. 2009, pp.1281-1288. (in Chinese)